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CNH: Collaborative Research: Direct and Indirect Coupling of Fisheries Through Economic, Regulatory, Environmental, and Ecological Linkages

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Submitting Official (if other than PD\PI):	Andrew J Pershing Principal Investigator
Submission Date:	11/27/2013
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Andrew J Pershing

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Accomplishments

*** What are the major goals of the project?**

Ecosystem-based fisheries management became a required component of US fisheries management in 2006, yet fisheries managers still struggle with how to include ecosystem considerations. Our project aimed to study the ecosystem-based fisheries management problem using a simplified representation of the cod, lobster, and herring fisheries in the Gulf of Maine as a model system. This system includes commercially and culturally important fisheries, but more importantly, these fisheries are linked by complex ecological and economic interactions. Cod are an important predator of both herring and lobsters, and several studies have suggested that the reduction of cod and other groundfish in the early 1990s contributed to the growth of the lobster population and the lobster fishery. Herring are, in turn, predators of cod larvae. The link between herring and lobster is entirely the result of humans. Herring are currently the main source of bait for the lobster fishery, and our previous work suggests that the growth of juveniles that can escape easily from lobster traps is enhanced in areas that are heavily fished.

The major goals of our project were to

1. develop a quantitative understanding of how physical, ecological and socioeconomic processes collectively influence the three species and their associated fisheries

2. integrate this understanding into models of the population and economic dynamics of this system and other fisheries for which these models may be applicable

3. develop an interactive educational experience to teach children about complex connections between fish and people.

* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

Major Activities: Our project combined field studies, analysis of existing time series, and both mathematical and numerical modeling of coupled natural and human systems. We also had a novel education program focused on 5th and 6th graders in Maine that was fully integrated into the project.

Field studies

Our field studies focused on documenting relative patterns of groundfish predation on lobsters and on how lobster behavior changes in their presence. Previous studies have noted the growth of the Maine lobster fishery occured as predators such as cod declined. We conducted tethering experiments in both coastal waters with reduced groundfish abundance and offshore banks with higher predator abundance. We also contrasted between offshore ledges that were closed vs. open to fishing. The attack rates on large lobsters were much higher on the offshore banks that were closed suggesting that these sites harbor larger predators. Meanwhile, predation rates on large lobsters in fished areas both inshore and offshore were higher. Our findings from offshore closed areas provide an insight into what may have been prevalent cod – lobster interactions in the past before groundfish abundance declined.

We also conducted diet analysis of cod from various locations around the Gulf of Maine and found that lobsters make up a very small proportion of the diet. Thus, direct predation from cod may not be that important in structuring lobster populations. An exception to this finding was that red cod, a putative ecotype of cod that differs in diet, movement behavior and body shape (Sherwood & Grabowski 2010), was found to feed more often on lobster than normal cod. Red cod are broadly distributed throughout inshore habitats (primarily shallow kelp) and may be an important predator on lobsters in the inshore.

In addition to direct predation, predators can induce changes in prey behavior such as decreased foraging activity and increased shelter use that reduce fitness. To test whether groundfish such as cod influence the behavior of lobsters, we set up an acoustic tracking array in a semi-enclosed lagoon. We then attached acoustic tags to several lobsters and monitored their movements in the enclosure for two weeks After this initial period, we added three cod to the enclosure. Because these cod escaped within 2 weeks we were able to compare the behavior of lobsters before, during, and after the addition of the cod. Even though the cod were too small to eat the lobsters, the lobsters reduced their movements and sought shelter in rocky areas (McMahan et al. 2013).

Finally, we conducted lobster tethering assay to examine the susceptibility of a range of lobster size classes to predation in Saco Bay, Maine. We also sampled the diet of striped bass using both stomach content and stable isotope analyses to determine the degree to which this highly migratory predator is exerting top-down forcing on lobsters. The most susceptible sizes of lobster were then exposed to three different fish predators (striped bass, cod, and sea raven) separately in experimental mesocosm trials. Through these experiments, juvenile lobsters were found to respond differently to different predators. Cod and sea ravens elicited strong sheltering behavior whereas striped bass, a pelagic predator in the Gulf of Maine elicited no response (Wilkinson 2012).

Environmental studies

We conducted a variety of studies to quantify the influence of environmental conditions on the early life history of the three species. We contributed to two studies that used physical-biological models to look at the distribution patterns of larval lobsters and larval cod (Incze et al. 2010, Churchill et al. 2011). We also analyzed historical data on the settlement of post-larval lobsters and related these patterns to atmospheric conditions over the Gulf of Maine. We found that much of the interannual variability in lobster settlement can be explained by late summer weather conditions, with high settlement associated with warm conditions and wind patterns that favor the accumulation of larvae (Pershing et al. 2012). The latter relationship is similar to one revealed in our larval cod modeling work.

Population modeling

The bulk of our population model work focused on quantitatively estimate the impact of environmental conditions, bait availability, and predator abundance on the lobster population (Zhang and Chen, 2012). We used the size-structured model currently used by the Atlantic States Fisheries Management Council's lobster assessment to evaluate different harvest control rules . We also modified this model to include increased growth of juveniles in response to heavy herring bait use for use in our coupled modeling studies (Zhang et al. 2012). We also continued our analysis of harvest control rules using a more advanced individual-based lobster population model (Chang et al. 2011). Finally, we developed a model of the spatial distribution of lobsters as a function of habitat, including temperature and bottom type (Chang et al. 2010).

Coupled natural and human systems modeling

We conducted a set of modeling studies moving from simpler analytical models to more complex and dynamic numerical models. We began with an analytical models focused on bioeconomic equilibrium. We explored how the equilibrium of a fishery is altered by dependence on another fishery for inputs, e.g. the dependence of the lobster fishery on herring for bait (Ryan et al. 2010). We also explored how the growth subsidy from the bait affected the equilibrium (Ryan et al. 2014).

We then developed an empirically parameterized bioeconomic model of the Maine lobster fishery, which we used to explore alternative management approaches. This model examined how the monthly patterns of effort in the lobster fishery emerge from the interaction between the catchability of lobsters, the depletion of legal sized lobsters during the year, and market conditions.

The numerical lobster fishery model was then integrated into a coupled model of the lobster and herring fisheries which enabled us to explore the importance of the linkages between the fisheries associated with the use of herring bait by the lobster fishery (Lehuta et al. 2014). The herring model explicitly modeled the spatial structure of the fishery, which includes two substocks of herring migrating between four management areas.

Finally, we developed a dynamical systems model of the cod, lobster, and herring populations and their associated fisheries. This model captured the full breadth of our study, but with less realism than our coupled lobster-herring model (Fitzpatrick, 2013).

Another general focus of our coupled natural and human system modeling was fishery management under uncertainty. Our modeling explored the risks and benefits of regulating catch at alternative spatial scales when the spatial dynamics and distribution of a fish metapopulation are uncertain. We first developed simpler biomass models (Holland and Herrera 2010) and later more complex age-structured models that allowed for asymmetric migration and recruitment (Holland and Herrera 2012). We also examined the challenges and benefits of incorporating additional spatial realism in management.

Education

The Gulf of Maine Research Institute operates a hands-on education experience called *LabVenture!*. The program serves 75% of Maine's 5th and 6th graders (10,000 students each year). Our project supported the development of the "Complex Systems" program that is starting its second year. Within the program, students learn about the potential impact of climate change on the Gulf of Maine, the response of lobsters to predatory fish like cod, and use a computer game to understand the economic and ecological trade-offs involved in fishing. Our project also supported a rigorous evaluation of the impact of the program on student learning, specifically, the ability of students to collaborate and to reason with evidence.

Specific Objectives:

The overall goal of our project was to understand how natural and human-induced linkages between cod, herring, and lobsters and their associated fisheries impact the dynamics of the system. Our six activity areas each had specific objectives that built towards this goal.

Field studies

Our field studies were designed to examine spatial patterns of lobster predation risk and the impact of cod and other predators on lobster activity and habitat selection. Both objectives contributed to the design of our coupled modeling studies.

Environmental studies

Our environmental studies focused on the sensitivity of the ecosystem to outside drivers. Our main objective was to understand the impact of changes in physical conditions such as winds, temperature, and currents on the success of early life stages of the three species.

Population modeling

The main goal of our population modeling work was to develop improved models of the lobster population to support our coupled modeling work and to further understand the dynamics of this fishery.

Coupled natural and human systems modeling

Our coupled modeling studies were intended to explore the dynamical consequences of particular linkages in the three-species system. We were particularly interested in understanding how changes in one fishery can affect the benefits from and sustainability of the other fisheries.

We also evaluated the potential benefits and risks of including of ignoring spatial structure in a managing a fish metapopulation with uncertain spatial dynamics and distribution.

Education

The main goal of our education initiative was to create interactive learning modules to teach aspects of complex systems research. We also aimed to evaluate the effectiveness of the hand-on learning experience employed in *LabVenture!*

Significant Results:

Field studies

Our field studies support the hypothesis that reduced groundfish predators has decreased predation pressure on lobsters in coastal Maine. Our field studies also documented significant behavioral changes in lobsters in the presence of groundfish. As coastal groundfish abundance declined, the reduction of these non-consumptive effects could explain the expansion of lobsters into unstructured habitat. Our study in Saco, Maine identified that small, juvenile lobsters are most susceptible to predation (Wilkinson 2012). In the lab, juvenile lobsters moved less and spent more time in shelter when in the presence of cod . In contrast, striped bass did not induce lobsters to alter their behavior. These predator-induced changes in behavior can result in less foraging activity, which may translate into reduced lobster growth and reproduction. Alternatively, the lack of a behavioral response to the presence of striped bass may make lobsters particularly vulnerable to this transient predator which starts to target lobsters at around 60-70 cm total length (Wilkinson 2012). Collectively, behavioral release from predators along with reduced predation rates and increased herring bait subsidies of sublegal lobsters are likely all contributing to the recent explosion in lobster populations (Grabowski et al. 2010, McMahan et al. 2013).

Our work has helped establish that red cod (first described by Bigelow and Schroeder) consume more benthic prey such as lobsters, have a deeper body typical of a more resident lifestyle, and grow more slowly than do olive (normal) cod (Sherwood and Grabowski 2010). Red cod also inhabit much shallower environments (particularly kelp beds) and are likely more resident than normal. The presence of multiple ecotypes within the population has direct implications for cod management. For example, closed areas likely have a disproportionate benefit for sedentary red cod. Additionally, there is a possibility that population structure of red cod is much more complex than currently recognized due to their presumed sedentary nature.

Environmental studies

We identified several mechanisms by which changes in the physical environment influence the early life history of our target species. We demonstrated that year-to-year differences in surface currents have a strong influence on settlement rates in lobster and alter the connection between population centers in both cod and lobster.

Population modeling

We used our lobster population dynamics models to explore different harvest control rules for the Maine lobster fishery. We found that rules that control mortality were more effective the rules that attempted to control catch. We also developed a robust habitat model for lobsters that explains seasonal, age, and sex-based movements in lobsters. Finally, we explored the potential impact of changes in physical conditions on lobster population dynamics with in our individual-based model. We found that warming could lead to higher yield-per-recruit as long as mortality rates do not also increase. Increasing the minimum legal size would be an effective tool for countering conditions with increased mortality.

Coupled natural and human systems modeling

An extensions of classic equilibrium bioeconomic models allowing for a two fishery system coupled by the dependence of a primary fishery on a secondary bait fishery exhibits important and non-intuitive differences from standard fishery models. Most importantly a tight interdependence of the two fisheries (i.e. the bait fishery providing the only cost-effective source of bait for the primary fishery) can result in counterintuitive results, e.g. an increase in price for the primary fishery can result in lower effort and higher biomass in equilibrium and either a higher or lower level of catch (Ryan et al. 2010). The growth stimulus provided by bait causes both optimal and open access catch and effort levels in the primary fishery to rise relative to the standard model. Failing to consider this effect could lead managers to set catch limits lower than optimal (Ryanet al. 2014).

We found that the monthly patterns of effort in the lobster fishery emerge from the interaction between the catchability of lobsters, the depletion of legal sized lobsters during the year, and market conditions. This creates incentives for excessive harvesting early in the season that greatly reduces the value of the fishery. Our work also suggests that reducing effort in the lobster fishery and moving some catch toward later in the year could nearly double profits with the same total catch. However lower harvest costs in summer and early fall still favor a concentration of landings in those months (Holland 2011a,b). The model also showed that managing with individual transferable quotas (ITQ), would fail to fully maximize profits from the fishery. In-season depletion and congestion externalities not resolved by a in ITQ can lead to intra-annual exploitation patterns that reduce profits by as much as 30% relative to optimal exploitation (Holland 2011a). Our modeling points out that additional regulations that influence the timing and location of harvests may sometimes be needed to incentivize optimal behavior.

Our coupled model of the lobster and herring fisheries showed that the use of herring as the primary bait for the lobster fishery can cause changes in economic, biological or regulatory conditions in one fishery to impact the other (Lehuta et al., 2014). However, we found that the impacts were not symmetric. If effort is increased in the lobster fishery, then increased demand for herring can cause significant reductions in the herring population. Changing the price or the availability of herring caused only a limited impact on effort, catch and profits in the lobster fishery as long as a reasonably priced substitute bait is available. However, because the derived demand for bait is inelastic, the herring fishery could potentially usurp some rent from the lobster fishery if it could maintain a price for herring just under the cost of the substitute bait.

Our dynamical modeling work describing the entire three-species system found that the highest economic value of the system is obtained when there is strong fishing pressure on cod. This reduces the abundance of cod, allowing the more valuable lobster fishery to increase. This result mimics the current state of the system, with high lobster landings, abundant herring, and low cod populations.

Our analysis of spatial management of a fishery metapopulation suggests that managing at the population level through a global catch limit can sometimes be more effective (more profitable and sustainable) then spatially refined management when spatial dynamics and distribution of the fish stock is uncertain (Holland and Herrera 2010, 2012). When exploitation rates are high, setting area-specific TACs can both increase profit and reduce biological risk. However, as exploitation rates are reduced to optimal levels, a global TAC appears to provide both higher profits and lower risk. Counter to intuition, connectivity between the populations tends to reinforce the benefits of area-specific TAC and make them preferable at relatively lower exploitation rates. The advantage of the global TAC is reduced when there is mixing and migration between the subpopulations, particularly when mixing is asymmetric. However, a regulator naïve to the nature of the true spatial dynamics (and hence the spatially optimal target fishing mortality rates) may still be better off employing a global TAC (Holland and Herrera 2012). This guidance could be valuable for fisheries where metapopulation structure is suspected but is uncertain.

Education

Our assessment of the *LabVenture!* education program found that it reinforces evidence-based learning and collaboration. The assessment results suggest that finding opportunities to prompt students to critically evaluate the quality should be added as a goal.

Key outcomes or Other achievements: Our project brought together oceanographers, ecologists, economists, and educational specialists. One of the exciting results from this collaboration was that it spawned several new research projects. Notably, we modeled our new Coastal SEES project (a collaboration between Pershing, Chen, Holland, and Lishness along with other colleagues from UMaine, GMRI, NOAA, and SUNY Stony Brook) on this CNH project and will be building on the coupled modeling framework we developed.

* What opportunities for training and professional development has the project provided?

This project supported five graduate students:

Rich Ryan (MS 2009, Department of Environmental and Natural Resource Economics at the University of Rhode Island) investigated the dynamics of the herring bait market.

Peter Stetson (MS 2011, School of Marine Sciences, University of Maine) contributed to the environmental analyses.

Jui-Han Chang (Ph. D. , School of Marine Sciences, University of Maine) incorporated bioeconomic components and the herring bait subsidy into the individual based lobster population dynamic model.

Marissa McMahan (MS 2011, School of Marine Sciences, University of Maine) investigated the behavioral response of lobster to cod. She is continuing this work as a Ph. D. student with Jonathan Grabowski at Northeastern University.

Dominic Fitzpatrick (MS 2013, School of Marine Sciences, University of Maine) developed the dynamical model of the full cod-lobster-herring system.

This project also supported Dr. Sigrid Lehuta as a postdoctoral associate at the Gulf of Maine Research Institute (2010-2012). Dr. Lehuta developed the detailed model of the population dynamics and economics of the lobster-herring system. She now has a permanent position as a scientist at IFREMER and continues to work on coupled natural and human systems problems in fisheries. This project also supported the field work of Erin Wilkinson at the University of New England who examined predation patterns on lobsters.

*** How have the results been disseminated to communities of interest?**

Our project was created to explore important aspects of ecosystem-based fisheries management. We have close connections with the fishing industry in New England and with fisheries management, both regionally and nationally, and we are using these connections to convey our results. Yong Chen's lobster population dynamics models serve as the main tool used in the assessment for this stock. The ability of these models to now use environmental data and to parameterize linkages with herring and lobster will enable ecosystem-based management of this fishery. Yong Chen and Jonathan Grabowski are both members of the Science and Statistical Committee of the New England Fisheries Management Council and are well positioned to bring an ecosystem approach into decisions within the region. Finally, Dan Holland, who conceived of this project, is now working for NOAA's Northwest Fisheries Science Center and is at the forefront of merging ecosystem and economic considerations into fisheries management.

In addition, we communicated our results at international meetings including the International Council for the Exploration of the Seas Annual Science Meeting, AGU/ASLO Ocean Sciences Meeting, the American Fisheries Society Annual Meeting. We also produced over 20 peer-reviewed publications and expect that several more will acknowledge this grant.

Products

Books

Book Chapters

Conference Papers and Presentations

Inventions
Nothing to report.

Journals
Chang, J. H., Chen, Y., Holland, D. and Grabowski, J (2010). Estimating spatial distribution of American lobster Homarus americanus using habitat variables.. *Marine Ecology Progress Series*. 420 145. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Chang, Y. J., Sun, C. L., Chen, Y., Zhang, Y. Y. and Yeh, S. Z. (2011). Incorporating climate changes into population dynamic modelling: an individual-based modelling approach for lobster.. *Canadian Journal of Fisheries and Aquatic Sciences*. 68 122. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Churchill, J. H., Runge, J. and Chen, C. S. (2011). Processes controlling retention of spring-spawned Atlantic cod (Gadus morhua) in the western Gulf of Maine and their relationship to an index of recruitment success.. *Fisheries Oceanography*. 20 32. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Grabowski, J. H., Clesceri, E. J., Baukus, A. J., Gaudette, J., Weber, M. and Yund, P. O. (2010). Use of Herring Bait to Farm Lobsters in the Gulf of Maine. *PLoS ONE*. 5 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Grabowski, J. H., Gaudette, J., Clesceri, E. J. and Yund, P. O. (2009). The role of food limitation in lobster population

dynamics in coastal Maine, United States, and New Brunswick, Canada. *New Zealand Journal of Marine and Freshwater Research*. 43 185. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Holland, D. S. (2011). Optimal Intra-annual Exploitation of the Maine Lobster Fishery. *Land Economics*. 87 699. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Holland, D. S. (2011). Planning for changing productivity and catchability in the Maine lobster fishery. *Fisheries Research*. 110 47. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Holland, D. S. and Herrera, G. E. (2010). BENEFITS AND RISKS OF INCREASED SPATIAL RESOLUTION IN THE MANAGEMENT OF FISHERY METAPOPULATIONS UNDER UNCERTAINTY. *Natural Resource Modeling*. 23 494. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Holland, D. S. and Herrera, G. E. (2012). he impact of age structure, uncertainty, and asymmetric spatial dynamics on regulatory performance in a fishery metapopulation. *Ecological Economics*. 77 207. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Incze, L.,Xue, H.,Wolff, N.,Xu, D.,Wilson, C., Steneck, R.,Wahle, R.,Lawton, P.,Pettigrew, N.,Chen, Y. (2010). Connectivity of lobster (Homarus americanus) populations in the coastal Gulf of Maine: part II. Coupled biophysical dynamics.. *Fisheries Oceanography*. 19 1. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Johnson, C. L.,Runge, J. A.,Curtis, K. A.,Durbin, E. G.,Hare, J. A.,Incze, L. S.,Link, J. S.,Melvin, G. D.,Ω'Brien, T. D.,Van Guelpen, L. (2011). Biodiversity and Ecosystem Function in the Gulf of Maine: Pattern and Role of Zooplankton and Pelagic Nekton. *PLoS ONE*. 6 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Kasperski, S. and Holland, D. S. (2013). Income diversification and risk for fishermen. *Proceedings of the National Academy of Sciences of the United States of America*. 110 2076. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Lehuta, S., Holland, D. S., Pershing, A. J. (). Investigating interconnected fisheries: A coupled model of the lobster and herring fisheries in New England. *Canadian Journal of Fisheries and Aquatic Sciences*. . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Mcgonigle, C., Grabowski, J. H., Brown, C. J., Weber, T. C. and Quinn, R. (2011). Detection of deep water benthic macroalgae using image-based classification techniques on multibeam backscatter at Cashes Ledge, Gulf of Maine, USA.. *Estuarine Coastal and Shelf Science*. 91 87. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Mcmahan, M. D., Cowan, D. F., Sherwood, G. D., Grabowski, J. H. and Chen, Y. (2012). EVALUATION OF CODED MICROWIRE TAG RETENTION IN JUVENILE AMERICAN LOBSTER, HOMARUS AMERICANUS. *Journal of Crustacean Biology*. 32 497. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Pershing, A. J., Christensen, L. B., Record, N. R., Sherwood, G. D. and Stetson, P. B. (2010). The Impact of Whaling on the Ocean Carbon Cycle: Why Bigger Was Better. *PLoS ONE*. 5 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Pershing, A. J., Wahle, R. A., Meyers, P. C. and Lawton, P. (2012). Large-scale coherence in New England lobster (Homarus americanus), settlement and associations with regional atmospheric conditions.. *Fisheries Oceanography*. 21 348. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Runge, J. A., Kovach, A. I., Churchill, J. H., Kerr, L. A., Morrison, J. R., Beardsley, R. C., Berlinsky, D. L., Chen, C. S., Cadrin, S. X., Davis, C. S., Ford, K. H., Grabowski, J. H., Howell, W. H., Ji, R. B., Jones, R. J., Pershing, A. J., Record, N. R., Thomas, A. C., Sherwood, G. D., Tallack, S. M. L., Townsend, D. W. (2010). Understanding climate impacts on recruitment and spatial dynamics of Atlantic cod in the Gulf of Maine: Integration of observations and modeling.. *Progress in Oceanography*. 87 251. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Ryan, R. W., Holland, D. S. and Herrera, G. E. (2010). Bioeconomic Equilibrium in a Bait-Constrained Fishery. *Marine Resource Economics*. 25 281. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Sherwood, G. D. and Grabowski, J. H. (2010). Exploring the life-history implications of colour variation in offshore Gulf of Maine cod (Gadus morhua).. *ICES Journal of Marine Science*. 67 1640. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Zhang, Y. Y. and Chen, Y. (2012). Effectiveness of Harvest Control Rules in Managing American Lobster Fishery in the Gulf of Maine. *North American Journal Of Fisheries Management*. 32 984. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Zhang, Y. Y., Chen, Y. and Chang, Y. J. (2011). Estimating biological reference points using individual-based per-recruit models for the Gulf of Maine American lobster, Homarus americanus, fishery. *Fisheries Research*. 108 385. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Zhang, Y. Y., Chen, Y. and Wilson, C. (2011). Developing and evaluating harvest control rules with different biological reference points for the American lobster (Homarus americanus) fishery in the Gulf of Maine. *ICES Journal of Marine Science*. 68 1511. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Zhang, Y. Y., Li, Y. K. and Chen, Y. (2012). Modeling the dynamics of ecosystem for the American lobster in the Gulf of Maine. *Aquatic Ecology*. 46 451. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses
Nothing to report.

Other Products
Nothing to report.

Other Publications

Patents
Nothing to report.

Technologies or Techniques
Nothing to report.

Thesis/Dissertations
Wilkinson, E. B.. *Consumptive and non-consumptive effects of predatory fishes on lobster in Southern Maine*. (2012). University of New England.. Acknowledgement of Federal Support = Yes

Fitzpatrick, D.. *DYNAMICAL MODELING OF FISH-FISHERY INTERACTIONS IN THE GULF OF MAINE.*. (2013). University of Maine. Acknowledgement of Federal Support = Yes

Websites
Nothing to report.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Pershing, Andrew	PD/PI	2
Chen, Yong	Co PD/PI	0
Runge, Jeffrey	Co PD/PI	0
Incze, Lewis	Co-Investigator	0
Fitzpatrick, Dominic	Graduate Student (research assistant)	12

Full details of individuals who have worked on the project:

Andrew J Pershing
Email: andrew.pershing@maine.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Led the final synthesis stage of the project, including advising postdoctoral scholar Sigrid Lehuta and graduate student Dominic Fitzpatrick

Funding Support: none

International Collaboration: No
International Travel: No

Yong Chen
Email: ychen@maine.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 0

Contribution to the Project: Led the development of the population dynamics models.

Funding Support: none

International Collaboration: No
International Travel: Yes, China - 0 years, 1 months, 0 days

Jeffrey Runge
Email: jeffrey.runge@maine.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 0

Contribution to the Project: Contributed knowledge of the plankton community in the North Atlantic, including larval fish and lobsters

Funding Support: none

International Collaboration: No
International Travel: Yes, Norway - 0 years, 1 months, 0 days

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Lewis Incze
Email: lewis.incze@maine.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Co-PI on the project (originally at the University of Southern Maine). Contributed to the environmental analysis and to the overall direction of the project

Funding Support: none

International Collaboration: No
International Travel: No

Dominic Fitzpatrick
Email: dominicjfitzpatrick@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Developed the dynamical system model

Funding Support: none

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Bowdoin College	Academic Institution	Brunswick, ME
Gulf of Maine Research Institute	Other Nonprofits	Portland, ME
NOAA NWFSC	Other Organizations (foreign or domestic)	Seattle, WA
Northeastern University	Academic Institution	Nahant, MA

Full details of organizations that have been involved as partners:

Bowdoin College

Organization Type: Academic Institution
Organization Location: Brunswick, ME

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Gulf of Maine Research Institute

Organization Type: Other Nonprofits
Organization Location: Portland, ME

Partner's Contribution to the Project:
Facilities
Collaborative Research
Personnel Exchanges

More Detail on Partner and Contribution:

NOAA NWFSC

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Seattle, WA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Northeastern University

Organization Type: Academic Institution
Organization Location: Nahant, MA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

What other collaborators or contacts have been involved?

YES

Impacts

What is the impact on the development of the principal discipline(s) of the project?

Understanding how one fished popualtion impacts another is a prerequisite for ecosystem based fisheries management. We developed a comprehensive understanding of how cod, lobster, and herring are connected by both natural linkages and through human actions. We found that not only are cod and other groundfish important predators on lobsters, but their mere presence is enough to alter lobster behavior. Both factors suggest that the explosion of lobsters and the lobster fishery in Maine over the last 20 years is related to the decline of coastal groundfish populations. We also quantified the relationship between the lobster and herring fisheries through the use of herring bait. This human-induced link leads to increased growth rates in the juvenile lobsters. The strong link between the fisheries means that changes in the management of one fishery can impact another, although in this case, the effects are not symmetric.

What is the impact on other disciplines?

Nothing to report.

What is the impact on the development of human resources?

Through our educational program, approximately 30,000 children in Maine will learn about complex systems research and about the connections between lobsters, cod, herring, and people in the Gulf of Maine.

This project supported five graduate students:

Rich Ryan (MS 2009, Department of Environmental and Natural Resource Economics at the University of Rhode Island) investigated the dynamics of the herring bait market.

Peter Stetson (MS 2011, School of Marine Sciences, University of Maine) contributed to the environmental analyses.

Jui-Han Chang (Ph. D. , School of Marine Sciences, University of Maine) incorporated bioeconomic components and the herring bait subsidy into the individual based lobster population dynamic model.

Marissa McMahan (MS 2011, School of Marine Sciences, University of Maine) investigated the behavioral response of lobster to cod. She is continuing this work as a Ph. D. student with Jonathan Grabowski at Northeastern University.

Dominic Fitzpatrick (MS 2013, School of Marine Sciences, University of Maine) developed the dynamical model of the full cod-lobster-herring system.

This project also supported Dr. Sigrid Lehuta as a postdoctoral associate at the Gulf of Maine Research Institute (2010-2012). Dr. Lehuta developed the detailed model of the population dynamics and economics of the lobster-herring system. She now has a permanent position as a scientist at IFREMER and continues to work on coupled natural and human systems problems in fisheries. This project also supported the field work of Erin Wilkinson at the University of New England who examined predation patterns on lobsters.

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?

Our project is directly relevant to the management of fisheries. Our studies demonstrate several mechanisms by which actions in one fishery can propagate to another. The coupled ecological-economic modeling approach we used provides a way to quantify these impacts.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.